High pressure, low temperature hydrogen tube trailers

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Project ID #
PD22

Overview

Timeline

- Start date: **October 2004**
- End date: **October 2011**
- Percent complete: **40%**

Budget

- Total project funding
  - DOE: **$950 k**
- Funding received in FY08:
  - **$400 k ($75 k to date)**
- Funding for FY07:
  - **400 k**

Barriers

- **F. Gaseous hydrogen storage and tube trailer delivery cost**
- **G. Storage tank materials and costs**

Targets

Meet DOE 2012 delivery targets:

- **Tube trailer delivery capacity: 700 kg**
- **Tube trailer operating pressure: 7000 psi**
- **Tube trailer capital cost: $300 k**

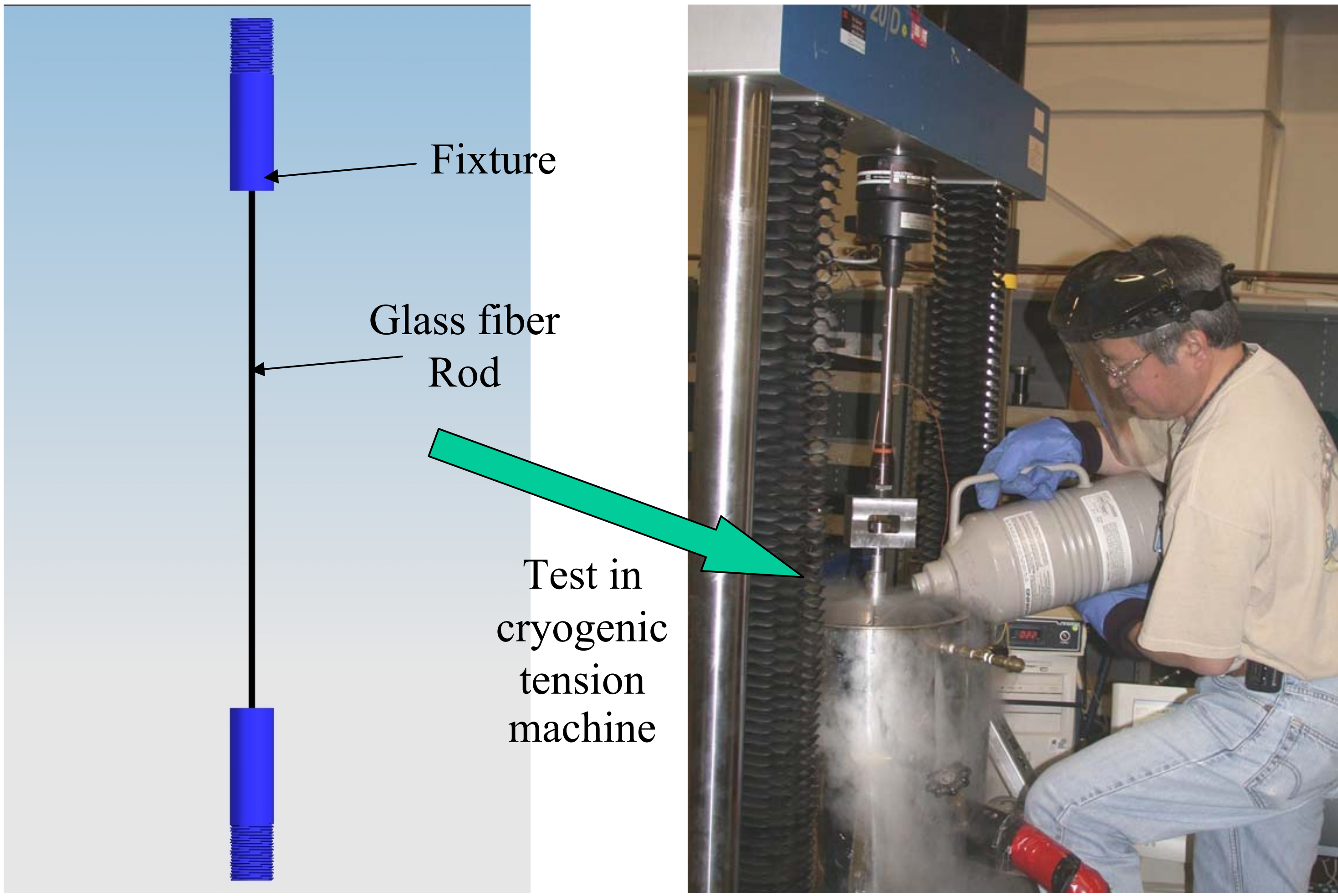
Partners

Ongoing joint projects with composite/vessel manufacturers

- **Spencer Composites**
- **SCI**
- **Quantum**

Glass fiber is weakened by water adsorbed into defects.

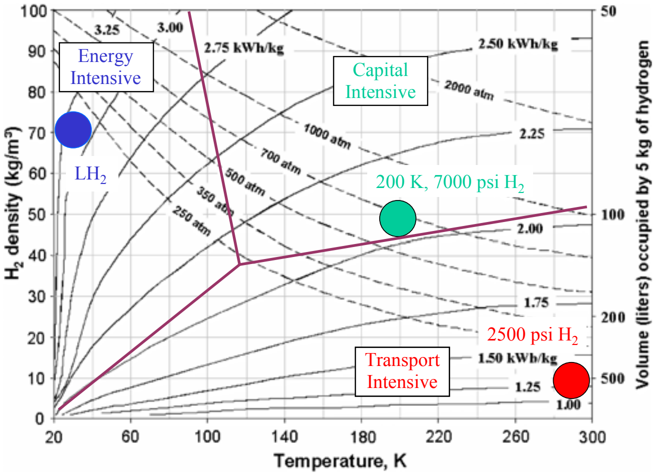
Reducing water effect through vacuum and/or cold operation considerably strengthens glass fiber (50-100%)



Objective: Demonstrate inexpensive hydrogen delivery through synergy between low temperature (200 K) hydrogen densification and glass fiber strengthening

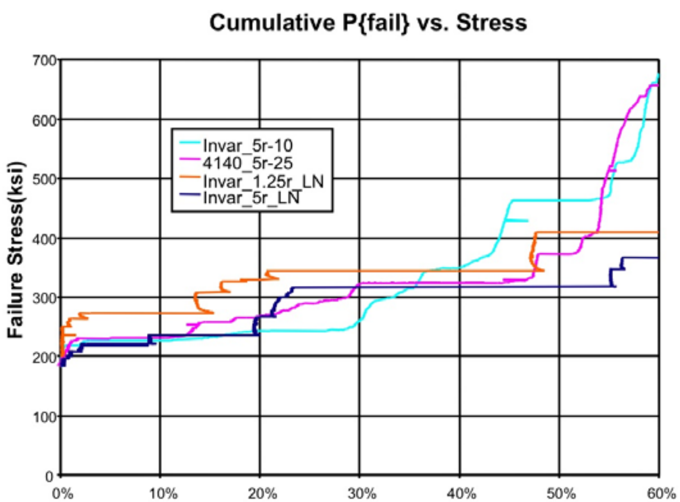
- **Colder temperatures (~200 K) increase density ~35% with small increases in theoretical storage energy requirements**
- **Low temperatures are synergistic with glass fiber composites**
  - **higher glass fiber strength (by 50%?) at 200 Kelvin (vs. 300 K)**
  - **higher gH_2 density increases mass-limited trailer capacity**
- **glass composites (~$1.50/kg) minimize material cost**
- **Increased pressure (7,000 psi) minimizes delivery costs**
- **Dispensing of cold hydrogen reduces vehicle vessel cost ~25%**

Milestones: Conduct experiments and analysis to demonstrate high performance, inexpensive glass fiber at low temperature



October 2006: Discovered favorable P-T conditions for H_2 delivery

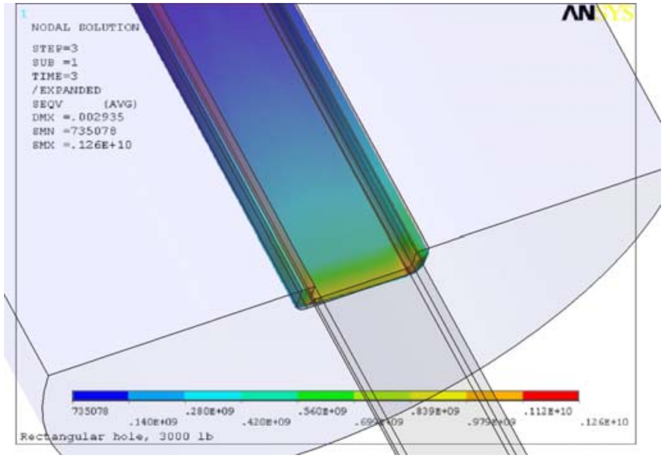
January 2008: Started cryogenic tension tests



March 2009: Demonstrate cold strengthening of preferred glass fibers

September 2011: Build and test optimal macrolattice container

Approach: Test glass fiber strength at cold/vacuum conditions enabling inexpensive, high performance vessels for H_2 delivery



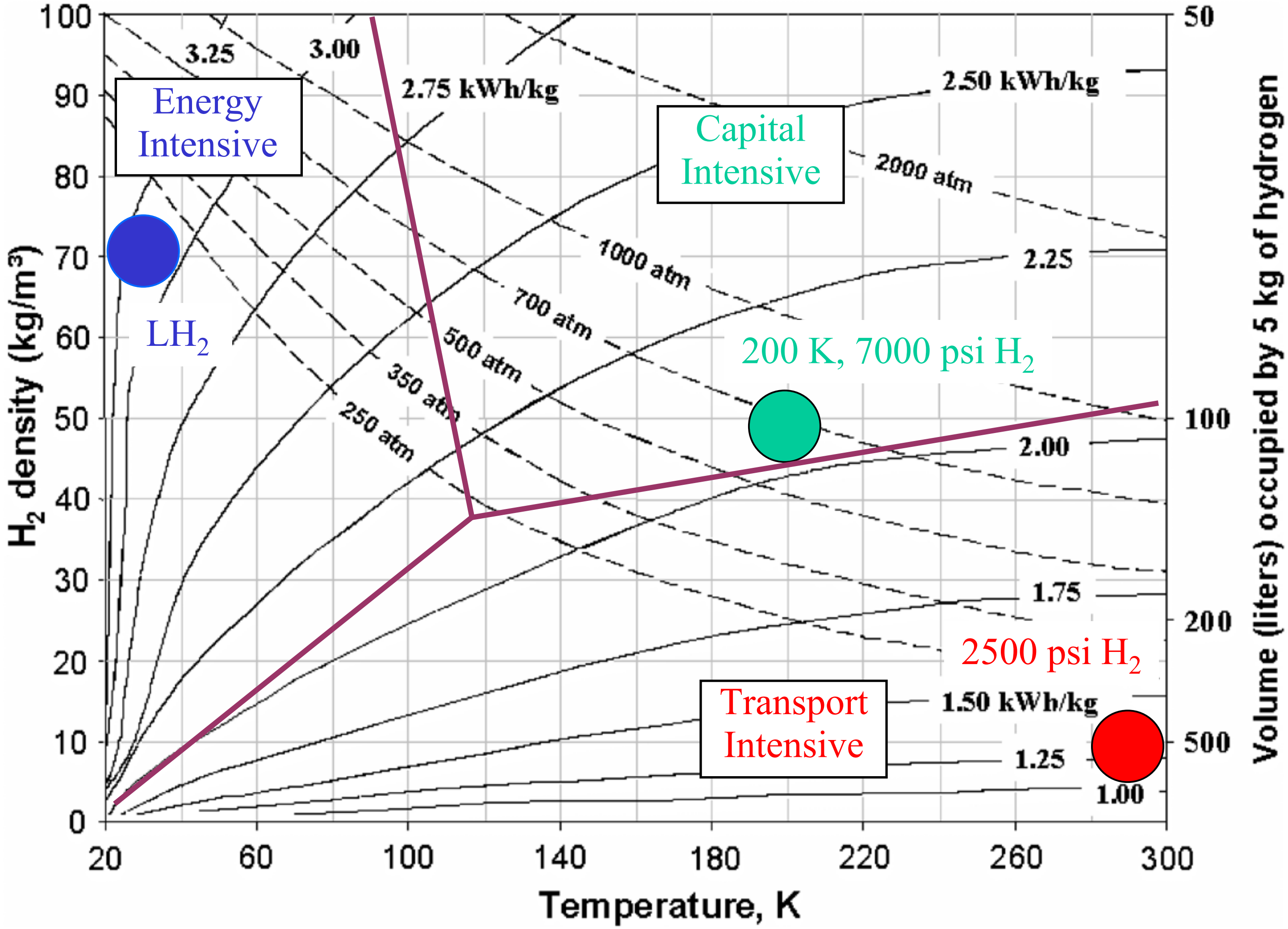
Stress analysis of fixtures

Prepare glass fiber samples

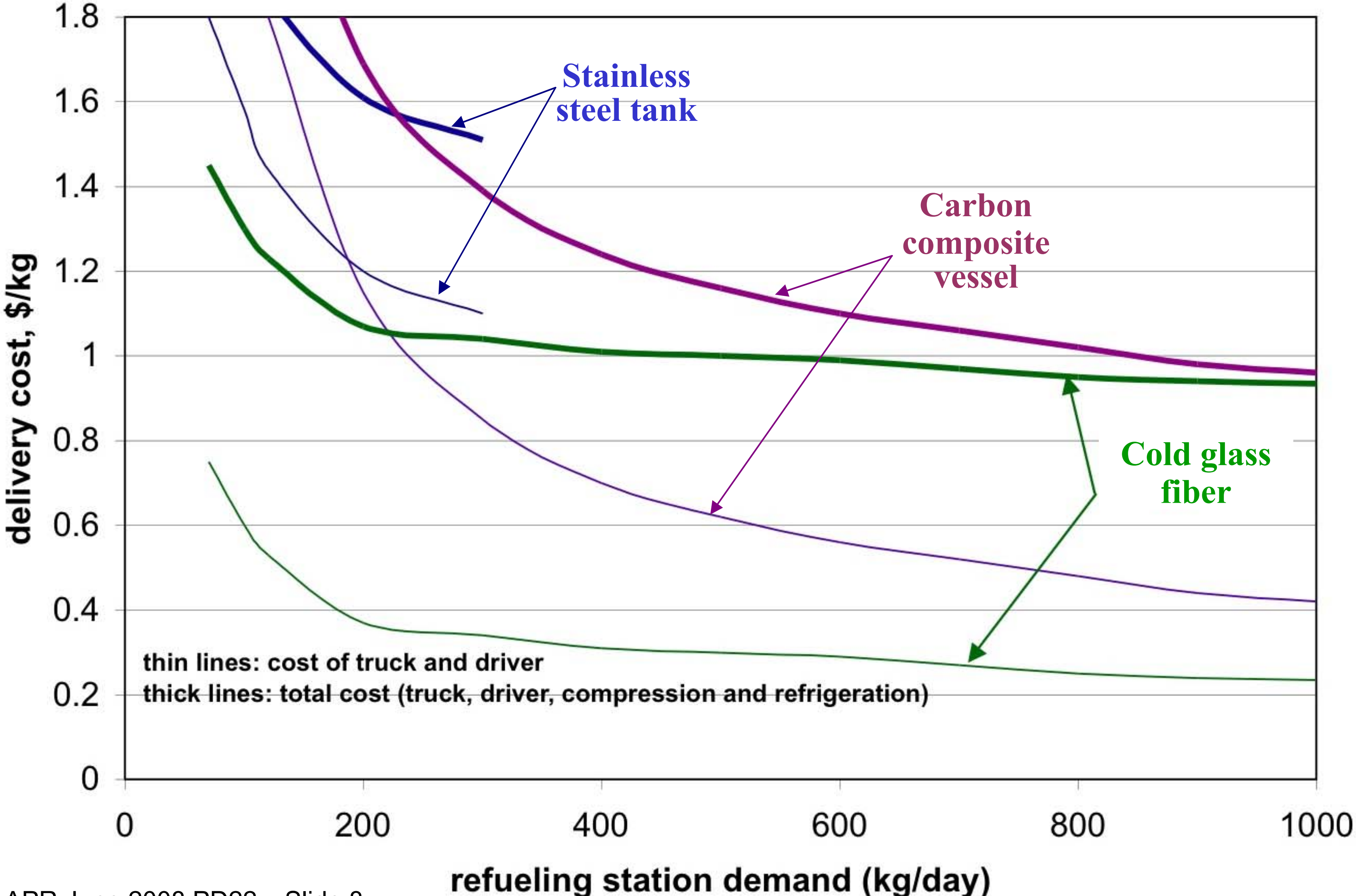
Tension test at cryogenic conditions

Data analysis

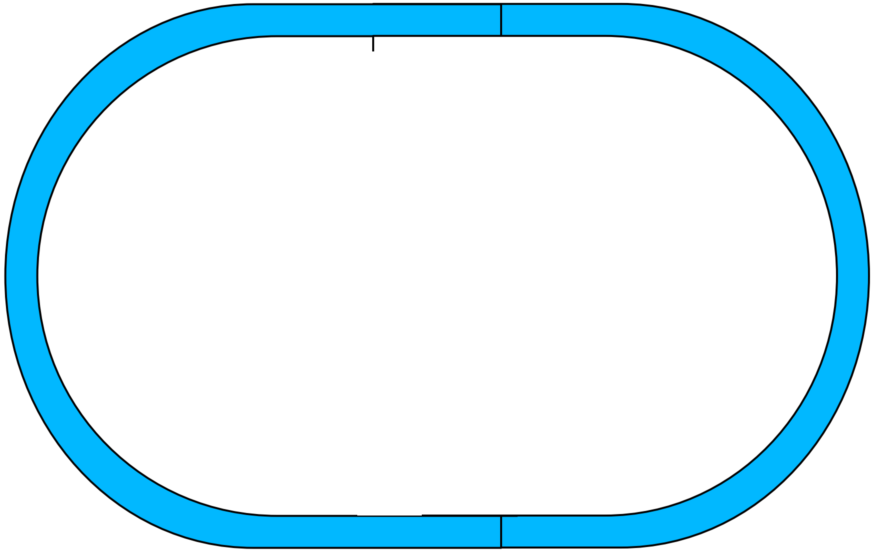
Accomplishments: we have identified an operating regime (200 K, 7000 psi) that shows promise for minimizing delivery cost



Cold glass fiber pressure vessels minimize tanker truck cost, enabling inexpensive hydrogen delivery

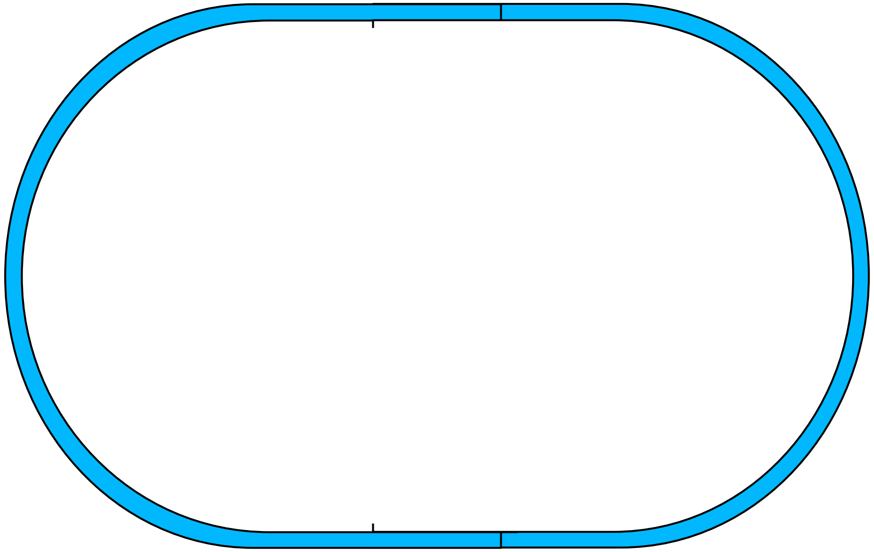


Dispensing cold hydrogen avoids overpressure during fill, reducing vessel cost by 25%.
Reduced vessel cost saves a driver \$0.20/kg H_2 (assuming a vessel that meets the 2010 DOE goal of \$4/kWh)



Today's automotive vessel

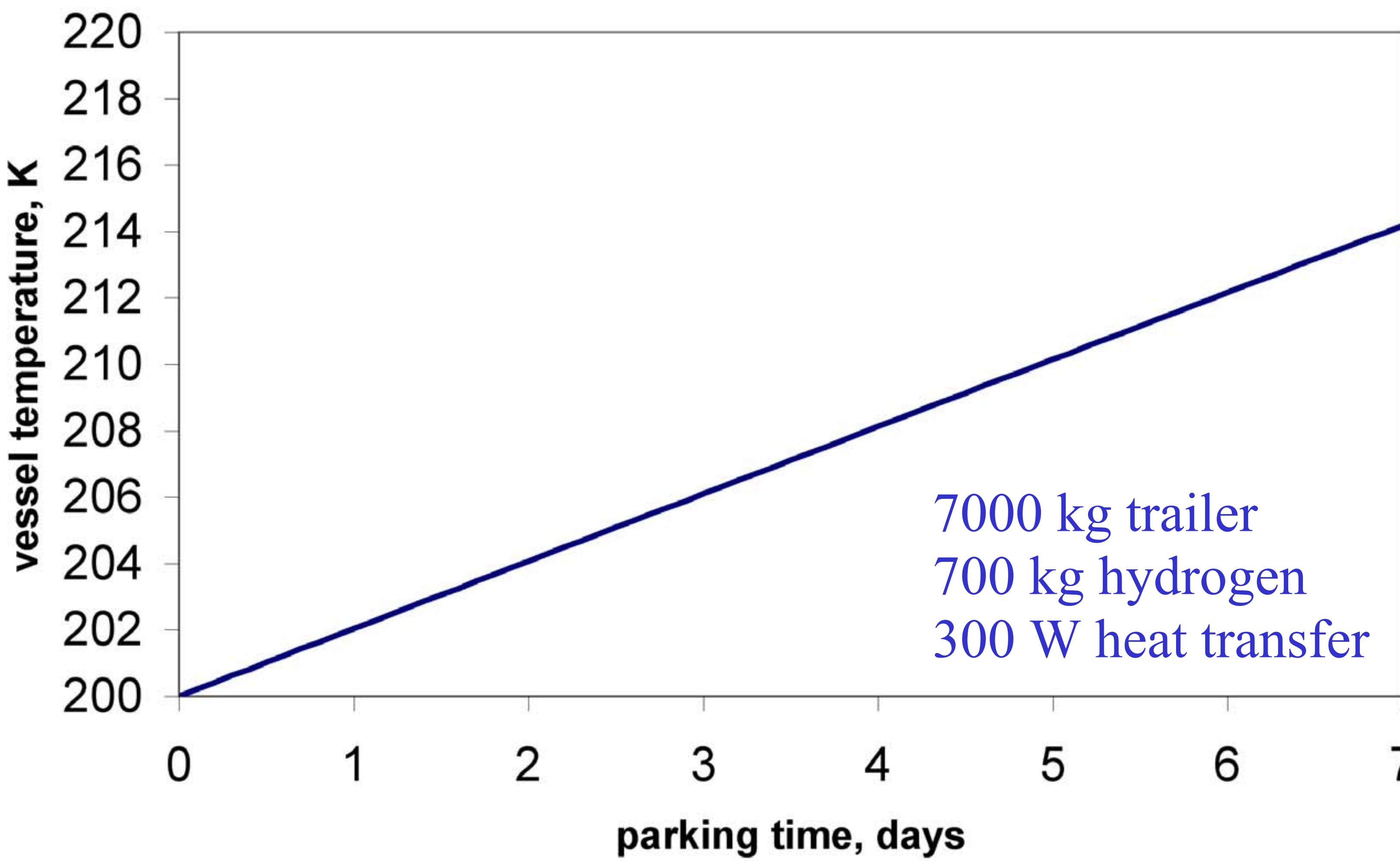
- Filled with warm hydrogen
- Service pressure: 5000 psi
- Fill pressure: 6250 psi
- Burst pressure: 11,250 psi
- Cost: \$ 1333 (2010 goal)



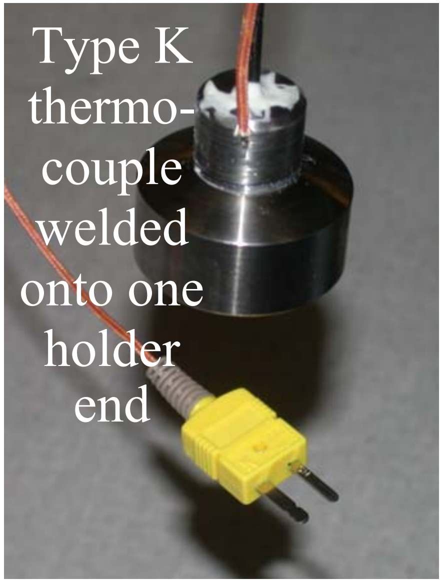
Future automotive vessel

- filled only with cold H_2
- Service pressure: 5000 psi
- Fill pressure: 5000 psi
- Burst pressure: 9,000 psi
- Cost: \$ 1066

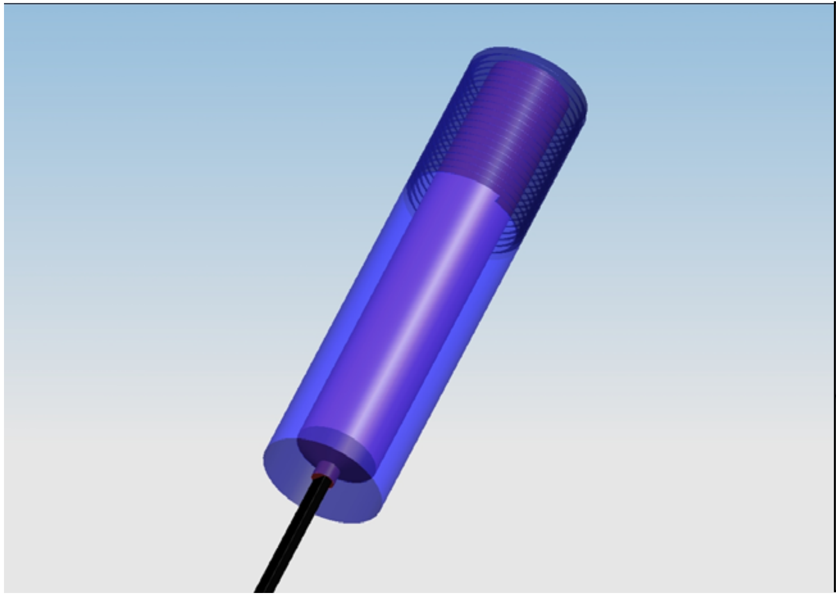
A parked/stranded delivery truck heats up very slowly due to heat transfer from the environment, avoiding increased risk of failure due to lower safety factor

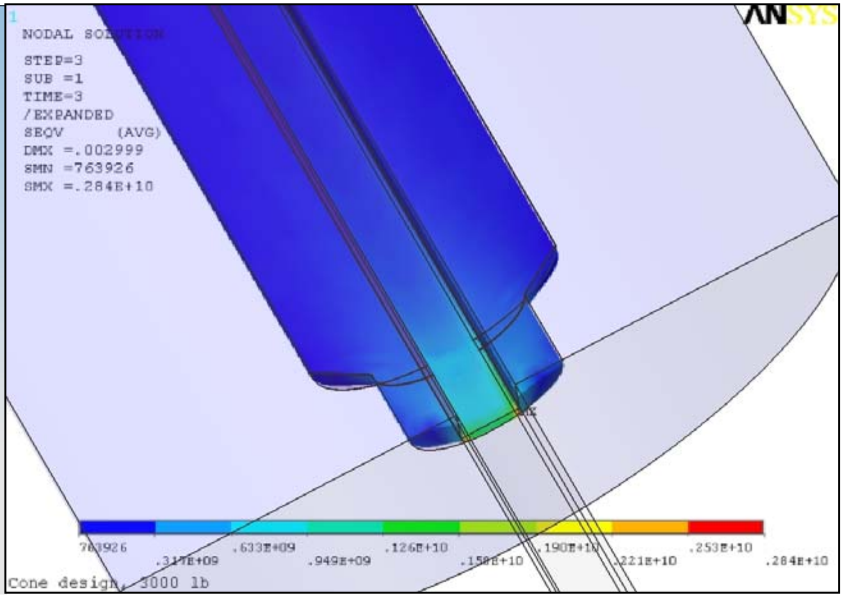


Need to measure strength of manufactured composite as a function of temperature and immersion time

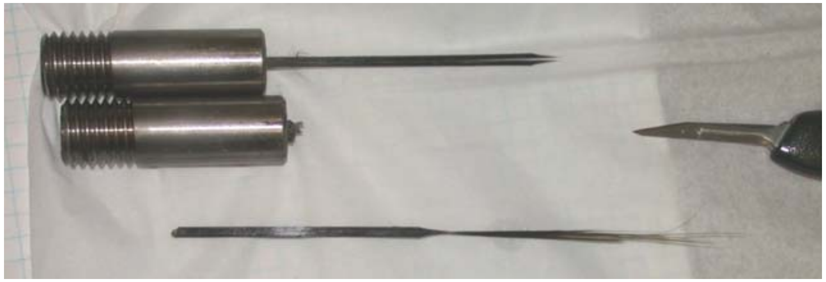


Designing fixtures is not straightforward due to high fiber strength. Our advanced analysis enabled design of optimized fixtures allowing successful sample testing.



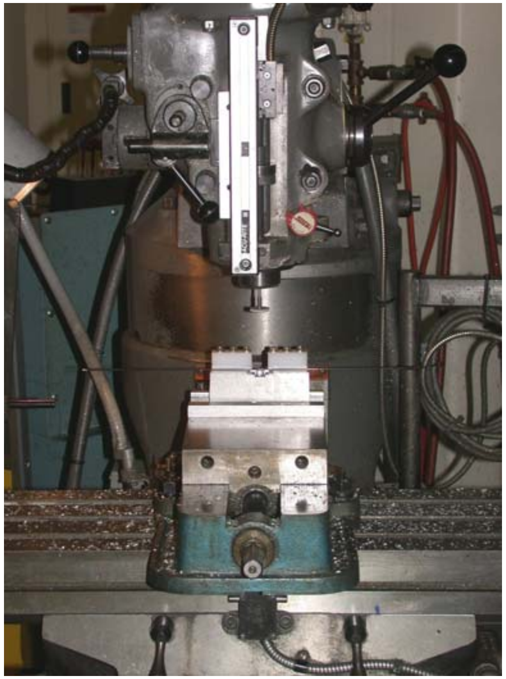


Conical cross section reduces stress concentration and allows higher tensile load



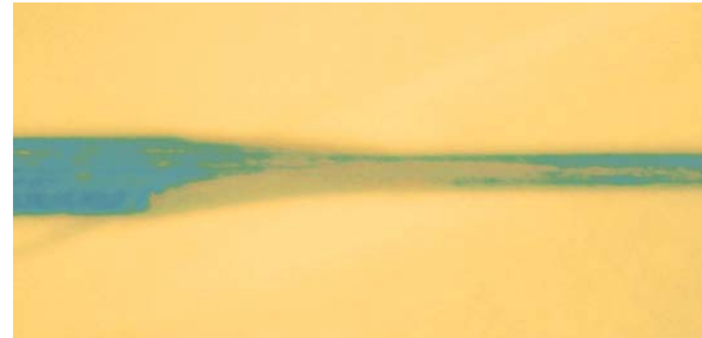
Conical design specimen holders after first cold tensile test success

Photographs Showing Failed Composite in Reduced-Area Region



Grinding Mill allows area reduction (AR) of both glued-up + unglued specimens

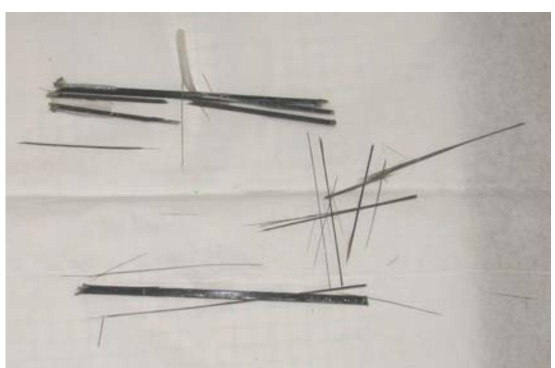
Earliest AR Section shows sheath of fibers damaged by grinding

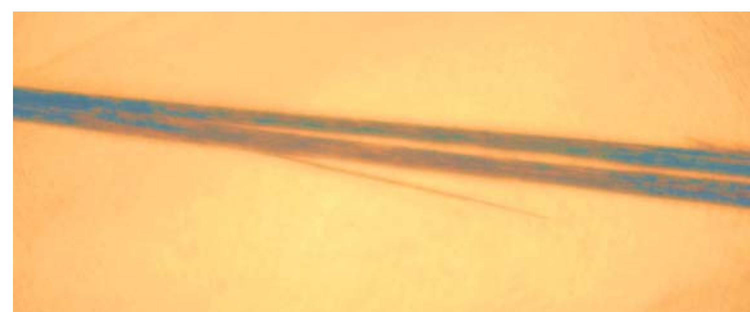


'Tongue' pulls out inches long !

Can image fiber damage sites, but section areas are not possible to measure

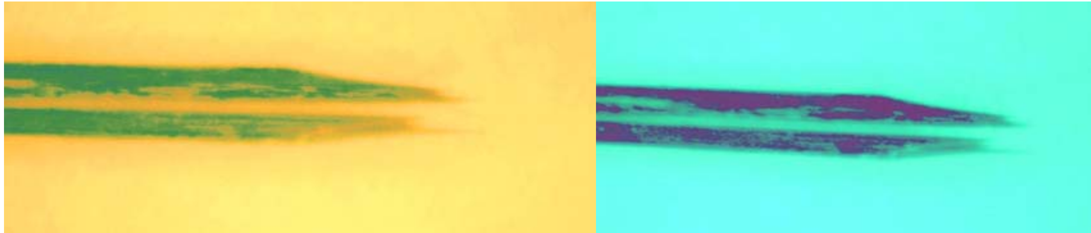
Only splinters remain from AR tensile specimens that failed in LN

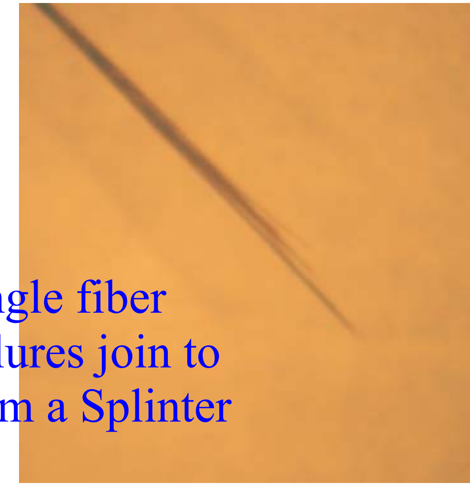




What's left after AR fails

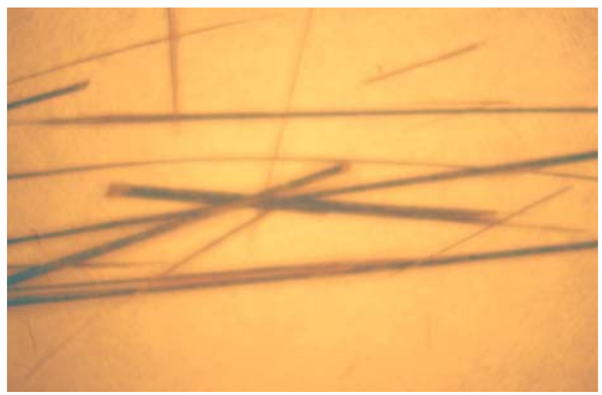
More Close-Up Photographs Show Failed Composite Phenomena

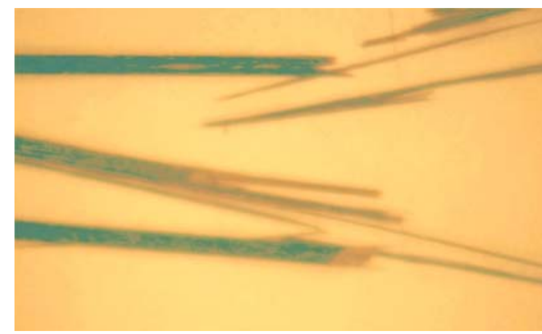




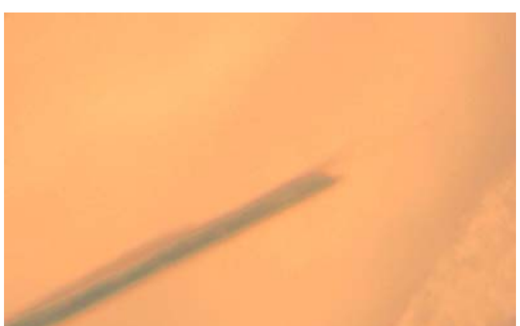
Single fiber failures join to form a Splinter

When failure occurs far from the AR section, a clean slot vacated of fiber is formed on the end opposite a ‘Tongue’ extending from the AR section to the defect where the highly loaded fibers that ran through the section are weakest



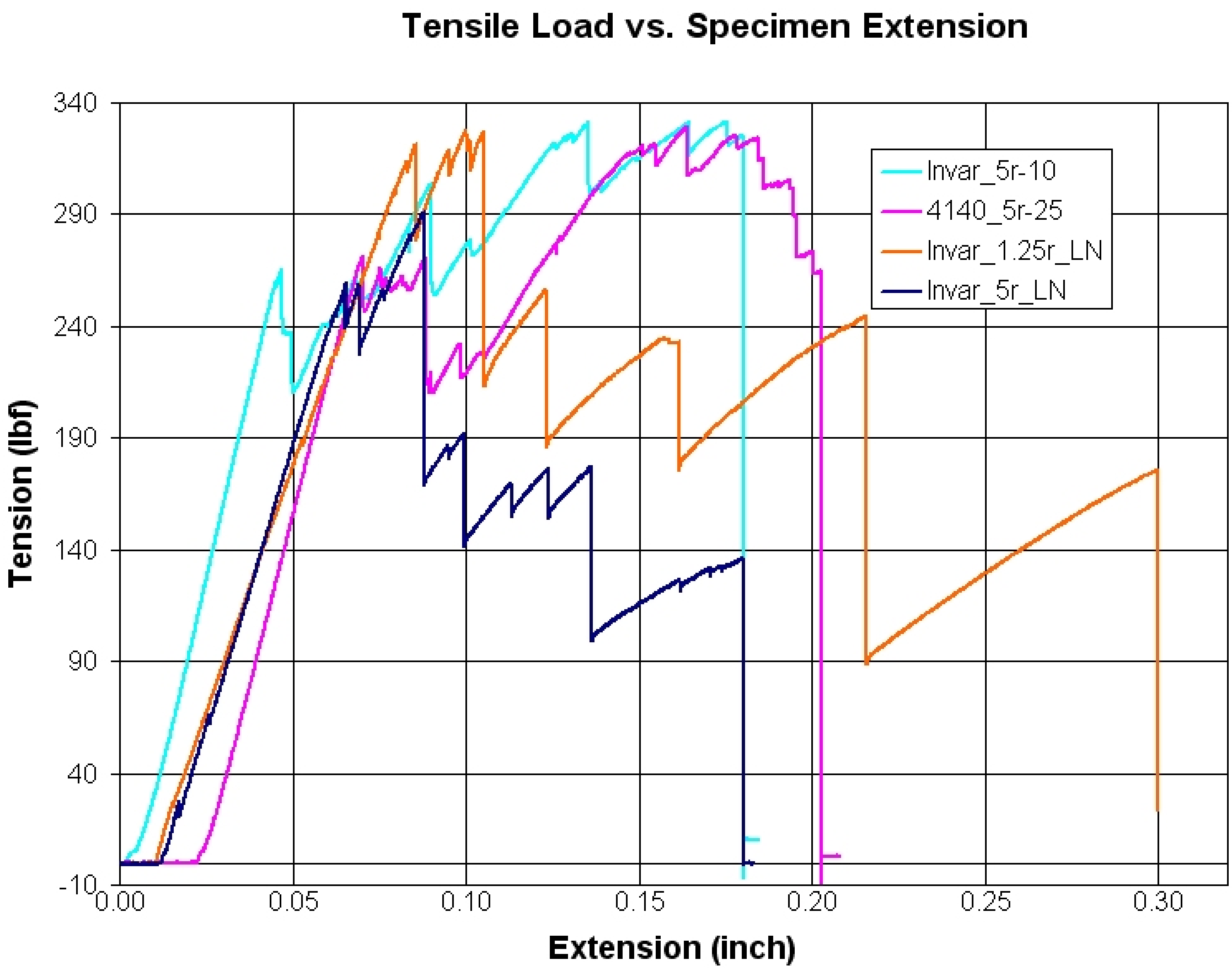


Only Splinters, no Tongue from fiber that failed near 0C

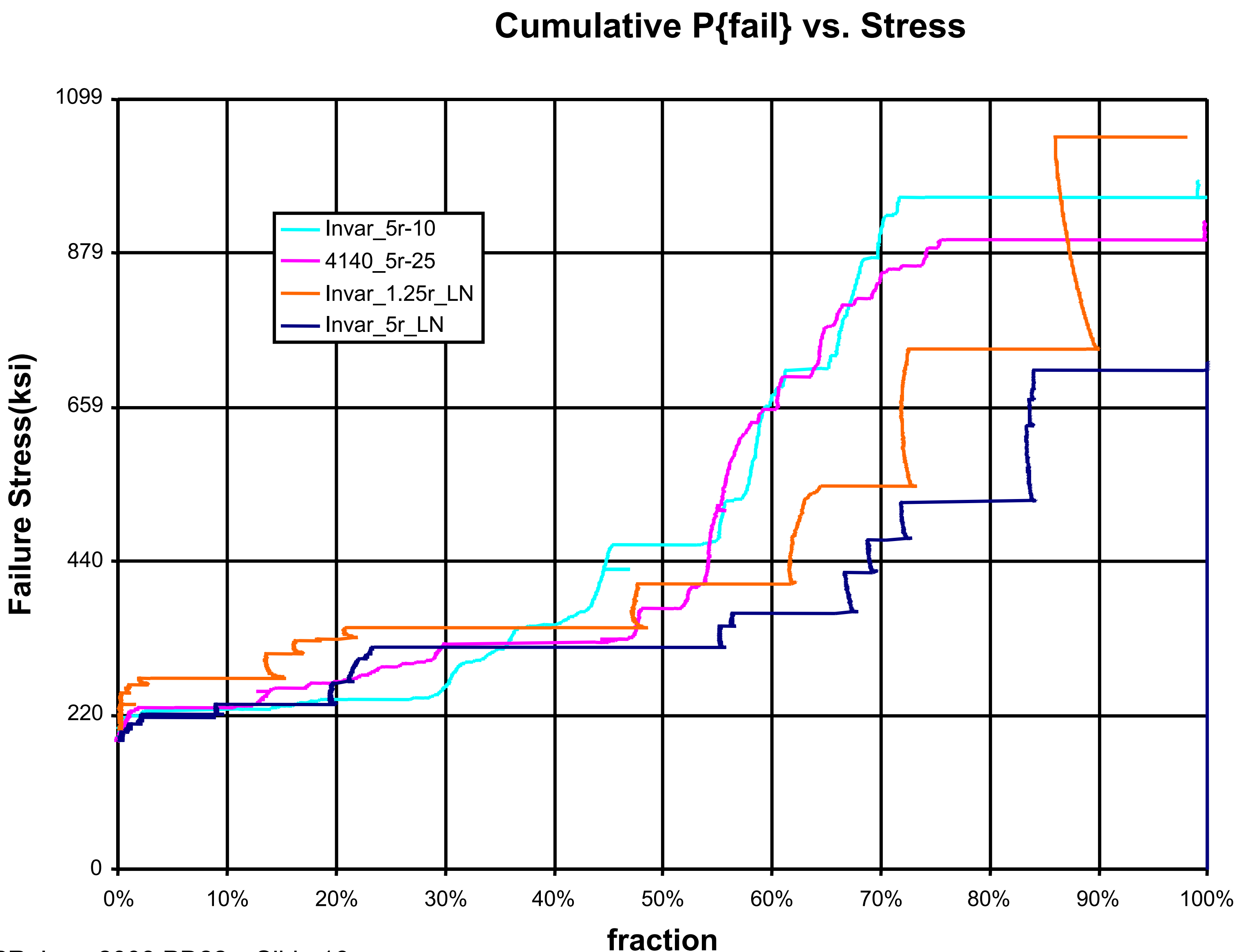


Ends of Tongues and Splinters show single and bundle fiber breakage, as well as possible defective manufacture (c.f. twisting)

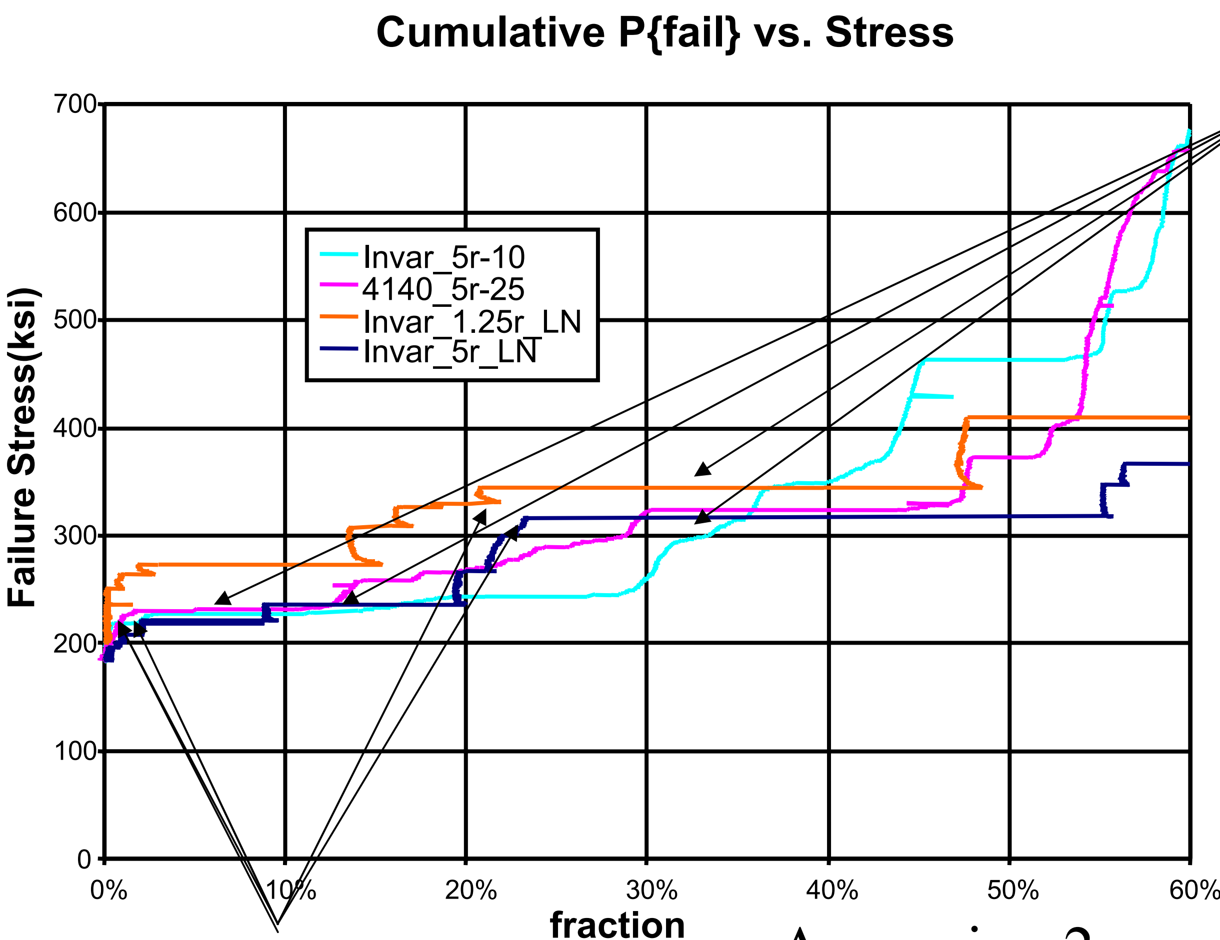
Raw Data from Tensile Testing of Best Recent Specimens



Test Data Reduced into Cumulative Probability of Failure Using Weibull Distribution Procedure from 1950's



Failure Stress for Core Fiber at Least 40% Higher at –162°C than at –10°C, and likely increases further with additional (diffusion) time spent at lower temperature



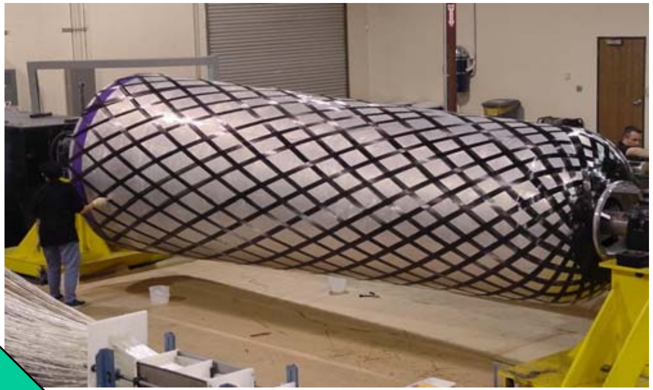
Plateaux in these curves occurs at nearly identical stresses for test specimens with same ambient and test section geometry despite fixture and epoxy differences

Damaged fiber fails early

Averaging 2 specimens/result yields 1.41 = 335/238

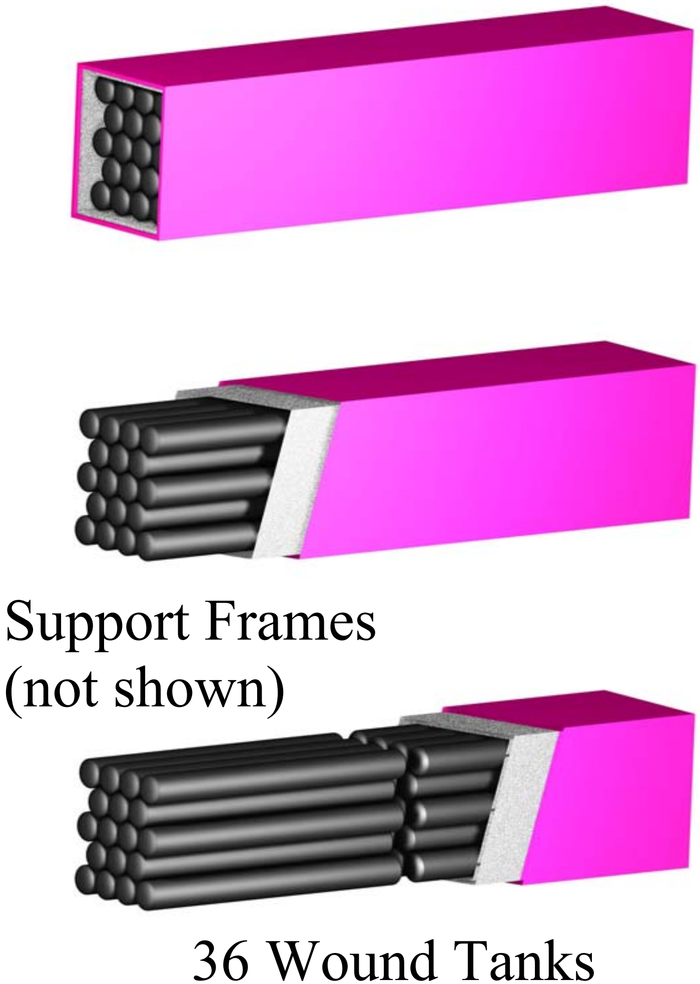
Future work: Complete cryogenic characterization of glass fiber leading to improved, low cost delivery vessels

cryogenic test



Inexpensive delivery vessels

Summary: Our synergistic approach to hydrogen delivery considerably reduces distribution cost



- ***Hydrogen cooled to 200 K densifies by 35% at low energetic cost***
- ***Inexpensive glass fiber strengthens by ~50% when cooled to 200 K***
- ***Cryo-compressed vessels have considerably larger thermal endurance (~10x) than liquid hydrogen tanks***
- ***Dispensing of cold (200 K) hydrogen reduces vehicle vessel cost by 25%***